

On the Electricity of Rain and Snow.

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In connection with a theory of the electricity of thunderstorms published in the 'Philosophical Transactions,'* measurements of the charges of rain were made in 1908, and it appeared advisable that these should be continued for a second year.

1. The removal of the Simla Meteorological Office near the end of 1908 offered a suitable site, and the hut containing the apparatus was accordingly dismantled and set up afresh in the grounds of the new building. In all essentials the arrangement of the instruments remained as described in the previous paper, but it was found after the removal and readjustment of the instruments that the electrical capacity of the rain receiver had changed from 141 cm. to 150 cm. The rain gauge was also readjusted so that each tip of the bucket now corresponded to 0.11 mm. of rain instead of 0.14, as before the alteration. The apparatus for recording the potential gradient was modified so that it could be used during fine weather for registering the normal potential gradient. This was effected by fixing a more powerful radium collector to the insulated rod passing out into the open. The new site was found to be much less frequented by spiders than the old, so that practically no difficulty was experienced from discharging of the apparatus by their webs. All the instruments worked satisfactorily throughout the rainy season and only a very few periods of rain were not successfully investigated.

2. The rainfall of the monsoon of 1908 was below the average, while that of 1909 was slightly above. In Simla it is well known that poor monsoons are accompanied by an abnormal number of thunderstorms; the rain during a good monsoon falls regularly and with only occasional breaks, while during a bad monsoon the periods of dry weather are longer and each ends with a thunderstorm. This fact was borne out by the measurements made in 1908 and 1909, for during the latter year the thunderstorms were neither so violent nor so frequent as during 1908.

The total amount of rain which fell during the storms investigated from April 19 to September 12, 1909, was 95.8 cm. The electrometer trace registered charged rain during 2212 two-minutes' intervals, during 1599 of which the electrometer recorded positive electricity and during 613 negative electricity.

* Series A, vol. 209, pp. 379—413, 1909.

The total quantity of positive electricity which fell on each square centimetre of surface was 21·7 electrostatic units and of negative electricity 6·2 units. Comparing these figures with the corresponding ones of the previous year, it will be seen that while the rainfall increased from 76·3 cm. to 95·8 cm. the total charge decreased slightly.

3. Perhaps the most important result obtained in the previous year's work was that more positive than negative electricity was brought down by the rain, the general impression up to that time having been that on the whole rain was negatively charged. In 1908 2·9 times as much positive as negative electricity fell, and the time during which positive rain fell was 2·3 times longer than that during which negatively charged rain fell*; the corresponding numbers for 1909 are 3·2 and 2·6 respectively, thus the previous result has been fully confirmed.

When charged rain is falling, the effect is equivalent to a vertical current of electricity; with positively charged rain the current may be considered to be positive and with negatively charged rain to be negative.

Table I shows the frequency of occurrence of different current densities.

Table I.

Current (unit 10^{-15} amp. per sq. cm.).	No. of two-minutes' intervals during which the current was		Ratio of number of positive intervals to number of negative intervals.
	Positive.	Negative.	
2—50	1263	522	2·4
50—100	198	66	3·0
100—150	68	18	3·8
150—200	22	3	7·3
>200	44	4	11·0

This table is in all essentials similar to the corresponding one for 1908, and, as before, the chief conclusions to be drawn are that—

(1) Large currents, both positive and negative, occur less often than small ones.

(2) The larger the current density the more the positive currents preponderate.

4. In Table II will be found the values of all positive currents having a

* N.B.—In consequence of a clerical error the number of occurrences of positive and negative electricity were wrongly stated in the previous paper. They should have been 1395 and 608 respectively instead of 1362 and 564; this gives a ratio of 2·3 instead of 2·4. The error is of no importance.

greater density than 300×10^{-15} ampere per square centimetre. There were no negative currents greater than this value.

Table II.

Positive currents.		Positive currents.	
Amps. $\times 10^{-15}$.	Date.	Amps. $\times 10^{-15}$.	Date.
312	April 18	374	June 20
337	" 18	454	" 20
312	" 18	478	" 20
312	" 18	356	" 20
400	June 5	564	" 27
> 613	" 15	319	" 27
331	" 15	324	July 11
307	" 18	357	" 11
441	" 19	357	" 11
429	" 19	357	" 11
> 613	" 19	313	Sept. 12
343	" 19	313	" 12

As regards the positive currents, this table is similar to the corresponding one for the previous monsoon, the only difference being that currents exceeding 600×10^{-15} are less frequent. It is noteworthy that not a single negative current exceeding 300×10^{-15} ampere was recorded; support is accordingly given to the impression, stated in the previous paper, that the storm of May 13, 1908, was entirely exceptional.

5. Table III shows the frequency with which rain having different charges per cubic centimetre was recorded.

Table III.

Charge per c.c. of rain, els. units.	No. of two-minutes' intervals during which the charge was		Ratio of the number of positive intervals to the number of negative intervals.
	Positive.	Negative.	
0.1—0.9	1116	381	2.9
1.0—1.9	104	66	1.6
2.0—2.9	56	28	2.0
3.0—3.9	21	21	} 1.2
4.0—4.9	15	7	
5.0—5.9	1	4	
> 6	1	1	

This table exhibits results similar to those of the corresponding table for 1908. Taking the two tables together, it may safely be said that there

is a tendency for the preponderance of positive over negative electricity to decrease as the charge per cubic centimetre of water increases. This result does not in any way contradict the second conclusion drawn from Table I; for while large currents are generally caused by heavy rain, high charges per cubic centimetre generally occur during light rain (see Table V).

6. In Table IV are given particulars of the two occasions on which charges exceeding 6 electrostatic units per cubic centimetre of water occurred. This table is much smaller than Table IV in the previous paper, which contained 34 entries.

Table IV.

Positive charge per c.c. of rain.		Negative charge per c.c. of rain.	
Els. units.	Date.	Els. units.	Date.
7·7	April 24	7·5	September 3

7. Perhaps the most interesting comparison is that between the rate of the rainfall and the charge which it carries.

Table V.

Rate of rainfall, mm. of rain in 2 minutes.	Rain with no charge.	Rain with positive charge.		Rain with negative charge.		Ratio of number of positive to number of negative two- minutes' intervals.	Ratio of the mean positive to the mean negative charge per c.c.
	No. of two-minutes' intervals.	No. of two-minutes' intervals.	Mean charge per c.c. of rain in els. units.	No. of two-minutes' intervals.	Mean charge per c.c. of rain in els. units.		
Less than 0·16	—	199	1·39	125	1·58	1·6	0·88
About 0·16	671	541	0·61	268	0·78	2·0	0·78
„ 0·38	94	195	0·26	71	0·34	2·7	0·59
„ 0·60	16	107	0·20	25	0·19	4·3	0·95
„ 0·82	2	81	0·18	6	0·24	13·5	1·34
„ 1·04	0	57	0·16	6	0·17	9·5	1·08
„ 1·26	0	49	0·23	7	0·13	7·0	1·76
„ 1·48	1	39	0·23	2	0·10	19·5	2·30
„ 1·70	0	16	0·21	1	0·07	16·0	3·00
Greater than 1·70	0	50	0·19	4	0·05	12·5	4·00

This table shows the only important difference between the results of the two years. In 1908 there was not a single case in which rain, falling at a greater rate than 1 mm. in two minutes, brought down a negative charge; in 1909 there were 14 such occurrences. Although the negative charges did not entirely cease with heavy rain in 1909, yet the table shows

that their frequency relatively to the frequency of positively charged rain became very small. The table, however, brings out a relationship which was not apparent in the previous work. It will be noticed that very light rain is relatively highly charged, and that the charge per cubic centimetre for both kinds of electricity decreases as the rate of rainfall increases up to 0.60 mm. in two minutes. With greater rates, however, positively and negatively charged rain behave differently; from 0.60 mm. in two minutes to the greatest rainfall rates measured the positive charge per cubic centimetre was practically the same, while with negatively charged rain the charge continues to decrease as the rate increases.

When considering in the previous paper the origin of the electricity of thunderstorms, considerable stress was laid on the absence of negative charge in heavy rain. These two new results do not affect materially the reasoning there used. In the centre of the thunderstorm, where the violent ascending currents give rise to a large deposition of water and consequently to a large separation of electricity, there must be considerable rainfall from the upper clouds which, according to the theory, are highly charged with negative electricity. The negative electricity brought down by this rain is, as a rule, far less than the positive charge on the rain from the head of the ascending current; but that the negative charge might occasionally, even in the heaviest rain, exceed the positive charge, will be expected when the complicated process in action is considered. The low negative charges per cubic centimetre of water in the heaviest rain indicate that the rain in these cases is probably a mixture of positively and negatively charged water, but that the negative electricity is in slight excess.

In order to investigate whether or not one sign of electricity preponderates in any one part of a storm, each period of rainfall was divided into four equal parts, and the number of times negative charge occurred in each was compared with the number of times positive charge occurred. The data published in Table VI of the previous paper showed that there was no marked difference in 1908, while the new data give an even smaller

Table VI.

	Ratio of occurrence of positive to negative charge		
	in 1st two-minutes' interval of each storm.	in the last two-minutes' interval of each storm.	During whole storm.
1908	2.1	2.1	2.3
1909	2.2	2.3	2.6

difference. Another method of investigating the same effect is that of seeing whether the storms tended to begin or end with negative electricity. This method was applied by counting the number of positive and negative signs of the electricity recorded in the first and last two-minutes' intervals of each storm, and it was found that the ratio obtained was practically the same as that for the whole storm. Thus there are no indications that negative electricity occurs more frequently during any particular period of a storm than during any other.

Turning now to the question of the relationship between the sign of the potential gradient and the sign of the electricity of the rain, we find that, as last year, the data do not allow of any definite relationship being traced. The data this year are considerably more numerous than they were previously, and from Table VII it will be seen that there is a very slight tendency for the charge upon the rain to be of the sign opposite to that of the potential gradient; but the small relationship might quite well be accidental, and no definite statement ought to be based on it.

Table VII.

	No. of two-minutes' intervals during which the potential was		Percentage occurrence of negative potential gradient.
	Positive.	Negative.	
Rain uncharged.....	314	630	67
„ charged positively	604	879	59
„ „ negatively	312	268	46

The data obtained during the two years have been combined in the following tables, and the conclusions which may be drawn have been expressed in a few short sentences:—

Table A.

Total quantity of rain investigated	172·1 cm.
Total quantity of positive electricity which fell on each square centimetre of surface	44·0 electrostatic units.
Total quantity of negative electricity which fell on each square centimetre of surface	13·8 „ „
Ratio of quantity of positive to quantity of negative electricity.....	3·2
Number of two-minutes' intervals during which the rain was positively charged	2994
Number of two-minutes' intervals during which the rain was negatively charged	1221
Ratio of the number of intervals with positively charged rain to the number with negatively charged rain	2·5

Table B.

Current in 10^{-15} amp. per sq. cm.	No. of two-minutes' intervals during which the current was		No. of positive intervals. No. of negative intervals.
	Positive.	Negative.	
2—50	2321	1033	2.2
50—100	363	114	3.2
100—150	149	35	4.3
150—200	55	8	6.9
>200	90 (84)*	26 (9)*	3.5 (9.4)*

* N.B.—If the abnormal storm of May 13, 1908, is not considered, the numbers in brackets should replace those against which they stand.

Table C.

Charge per c.c. of rain, els. units.	No. of two-minutes' intervals during which the charge was		No. of positive intervals. No. of negative intervals.
	Positive.	Negative.	
0.1—0.9	1953	686	2.8
1.0—1.9	252	122	2.1
2.0—2.9	108	53	2.0
3.0—3.9	60	27	} 1.6
4.0—4.9	24	15	
5.0—5.9	10	7	
6.0 and 76.0	15	21	

Table D.

Approximate rate of rainfall, mm. of rain in 2 minutes.	Rain with no charge.	Rain with positive charge.		Rain with negative charge.		Ratio of number of positive to number of negative two- minutes' intervals.	Ratio of mean positive charge per c.c. to mean negative charge per c.c.
	No. of two-minutes' intervals.	No. of two-minutes' intervals.	Mean charge per c.c. of rain in els. units.	No. of two-minutes' intervals.	Mean charge per c.c. of rain in els. units.		
<0.16	—	386	1.52	293	1.92	1.3	0.8
0.16	1112	818	0.74	420	0.87	1.9	0.8
0.38	300	509	0.40	159	0.41	3.2	1.0
0.60	44	231	0.21	50	0.33	4.6	0.6
0.82	4	126	0.19	13	0.15	9.7	1.3
1.04	0	104	0.24	10	0.11	10.4	2.2
1.26	0	63	0.26	7	0.13	9.0	2.0
1.48	1	63	0.26	2	0.10	31.5	2.6
1.70	0	27	0.28	1	0.10	27.0	2.8
>1.70	0	74	0.21	4	0.05	18.5	4.2

Table E.

	No. of two-minutes' intervals during which the potential gradient was		Percentage occurrence of negative potential gradient.
	Positive.	Negative.	
Rain uncharged.....	559	1298	70
„ charged positively	871	1316	60
„ „ negatively	429	484	53
	1859	3098	

Conclusions.

(1) The electricity brought down by the rain was sometimes positive and sometimes negative (Table A).

(2) The total quantity of positive electricity brought down by the rain was 3.2 times greater than the total quantity of negative electricity (Table A).

(3) The period during which positively charged rain fell was 2.5 times longer than the period during which negatively charged rain fell (Table A).

(4) Treating charged rain as equivalent to a vertical current of electricity, the current densities were generally smaller than 4×10^{-15} ampere per square centimetre; but on a few occasions greater current densities, both positive and negative, were recorded (Table B).

(5) Negative currents occurred less frequently than positive currents, and the greater the current density the greater the preponderance of the positive currents (Table B).

(6) The charge carried by the rain was generally less than 6 electrostatic units per cubic centimetre of water, but larger charges were occasionally recorded, and in one exceptional storm (May 13, 1908) the negative charge exceeded 19 electrostatic units per cubic centimetre (Table C).

(7) As stated in (3) above, positive electricity was recorded more frequently than negative, but the excess was the less marked the higher the charge on the rain (Table C).

(8) With all rates of rainfall, positively charged rain occurred more frequently than negatively charged rain, and the relative frequency of positively charged rain increased rapidly with increased rate of rainfall. With rainfall of less than about 1 mm. in two minutes, positively charged rain occurred twice as often as negatively charged rain, while with greater intensities it occurred 14 times as often (Table D).

(9) When the rain was falling at a less rate than about 0·6 mm. in two minutes, the charge per cubic centimetre of water decreased as the intensity of the rain increased (Table D).

(10) With rainfall of greater intensity than about 0·6 mm. in two minutes, the positive charge carried per cubic centimetre of water was independent of the rate of rainfall, while the negative charge carried decreased as the rate of rainfall increased (Table D).

(11) During periods of rainfall the potential gradient was more often negative than positive, but there were no clear indications of a relationship between the sign of the charge on the rain and the sign of the potential gradient (Table E).

(12) The data do not suggest that negative electricity occurs more frequently during any particular period of a storm than during any other.

Electricity of Snowfall.

During winter a certain amount of snow falls in Simla, and although the apparatus used in the work described above was not designed for measuring the electricity of snow, it was not impossible to make some qualitative measurements. Owing to the snow remaining in the receiver, the rain-gauge did not record the quantity which fell ; therefore no continuous record was obtained of the quantity of snow corresponding to the charge recorded ; hence the charge per gramme of snow could not be determined.

Snow fell on nine days between December 23, 1908, and February 3, 1909. On most of the days the snow was accompanied by thunder and lightning, and was generally mixed with a considerable amount of soft hail (German, *Graupel*).

As in the case of rainfall, the quantity of positive charge exceeded the quantity of negative, and positive charges were brought down during longer periods than negative.

Table VIII.

	Positive.	Negative.	Ratio.
Total quantity of electricity in electrostatic units	21·1	5·8	3·6
No. of two-minutes' intervals	488	229	2·1

The most striking fact was the excessive quantity of electricity brought down by the snow, for although snowfall only occurred during 717 two-minutes' intervals the above table shows that the total electricity recorded

was little short of that brought down by the rain during the whole monsoon. The following current densities were recorded :—

Table IX.

Current (unit 10^{-13} amp. per sq. cm.).	No. of two-minutes' intervals during which the charge was		No. of positive intervals. No. of negative intervals.
	Positive.	Negative.	
2—50	254	152	1·7
50—100	74	29	2·6
100—150	34	7	4·9
150—200	27	11	2·5
>200	95	29	3·3

On comparing this table with Table A given above, it will be seen that the proportion of large currents during snowfall is much greater than during rain.

Although, for the reason stated above, it was impossible to determine continuously the charge per gramme of the snow, there were a few intervals during which the amount of the snowfall was obtained by melting the snow collected in the receiver. Adding the total charge received, irrespective of sign, and dividing by the total snowfall, the following mean charges per gramme result.

Table X.

Date.	Duration of snowfall.	Amount of snowfall (in cm. of rain).	Total charge irrespective of sign in els. units.	Mean charge per gramme of snow in els. units.
	h. m.			
24.12.08	9 26	1·82	7·24	3·9
10. 1.09	1 28	0·84	1·39	1·7
10. 1.09	0 26	0·17	0·61	3·6
10. 1.09	1 24	0·42	0·38	0·9
24. 1.09 }	7 10	1·32	5·55	4·2
25. 1.09 }				

These mean charges are higher than any obtained during equal periods of rainfall, and it must therefore be concluded that snow is more highly charged than rain.

Conclusions.

As far as can be judged from the few measurements made during the winter of 1908—09, it would appear that :—

(1) More positive than negative electricity is brought down by snow in the proportion of about 3·6 to 1.

(2) Positively charged snow falls more often than negatively charged.

(3) The vertical electric currents during snowstorms are on the average larger than during rainfall.

(4) The charge per unit mass of precipitation is larger during snowfall than during rainfall.

Long-Period Determination of the Rate of Production of Helium from Radium.

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In a previous communication* the rate of the production of helium from 70 milligrammes of radium chloride was determined by a succession of observations on the growth of pressure measured by a McLeod gauge. These observations extended over a period of about six weeks. It was thought desirable to make an experiment to determine the amount of helium resulting from this same sample of radium, after standing in a sealed bulb for an extended period. For this purpose the bulb containing the radium chloride was sealed off at the conclusion of the above-mentioned experiment of 1908 and kept for nine months. In order to measure the helium thus produced it was necessary to devise a vacuum-tight joint between the sealed radium bulb and a McLeod gauge so constructed that, after thoroughly exhausting the gauge, the drawn-out end of the radium bulb could be broken off, thus allowing the pressure of the accumulated helium in the radium bulb to be rapidly determined.

Such a joint is shown in fig. 1. A is the small bottle containing the radium chloride resting in the cylindrical bulb B with long tubular neck drawn out to a capillary, and sealed off at C at the conclusion of the first experiment. This tubular neck slides with slight clearance into the drawn-out neck of another cylindrical bulb D of stout glass, and is attached to it by a short, stout, indiarubber connection protected by a glass mercury cup M, previously fixed as shown on the neck of the radium bulb. This drawn-out neck is so shaped that the radium bulb can be readily rocked in a vertical plane about the neck as pivot within the limits of the diameter of D when so connected.

* 'Roy. Soc. Proc.,' A, vol. 81, p. 280, 1908.